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PREPRINT

USE OF PRECAST CONCRETE WALLS FOR BLAST PROTECTION OF STEEL STUD CONSTRUCTION

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14. ABSTRACT

This research study examines the response of a steel stud wall system and the use of an exterior precast concrete panel system for blast protection. The blast resistant system consists of a series of precast concrete panels installed in front of a conventional exterior stud wall and connected to the foundation at ground level and to the steel building frame beams at the top of the wall. The experimental investigation consists of two explosive detonations representing a "relatively low" blast level and a "very high" level of blast as defined by the Army Technical Manual 5-853-01. A bare stud wall and a precast concrete protected stud wall are both examined at the high and low level of threat. The research results show that the precast wall system provides an effective system protection for exterior walls. The research also shows that the metal stud wall system retains a significant degree of resilience and that the corresponding "Levels of Protection" as defined by UFC 04-0101-1 may be too conservative at low blast levels.

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Abstract

This research study examines the response of a steel stud wall system and the use of an exterior precast concrete panel system for blast protection. The blast resistant system consists of a series of precast concrete panels installed in front of a conventional exterior stud wall and connected to the foundation at ground level and to the steel building frame beams at the top of the wall. The experimental investigation consists of two explosive detonations representing a relatively "low" blast level and a "high" level of blast. A bare stud wall and a precast concrete protected stud wall are both examined at the high and low level of threat. The research results show that the precast wall system provides an effective system protection for exterior walls. The research also shows that the metal stud wall system retains a significant degree of resilience and that the corresponding "Levels of Protection" as defined by UFC 04-0101-1 may be too conservative at low blast levels.

Introduction

The use of lightweight steel studs for exterior walls is a common construction practice in the United States. While this method of building fabrication provides many benefits such as fire, insect and weather resistance, the low weight and laterally weak floor connections give it poor performance in a blast sensitive environment. The widespread use of this construction method combined with a greater need for blast resistant protection has prompted the development of a number of retrofit methodologies. This includes enhanced anchorage methods for the studs as well as the installation of coatings and sheet catch-systems on the interior face of the wall [6].

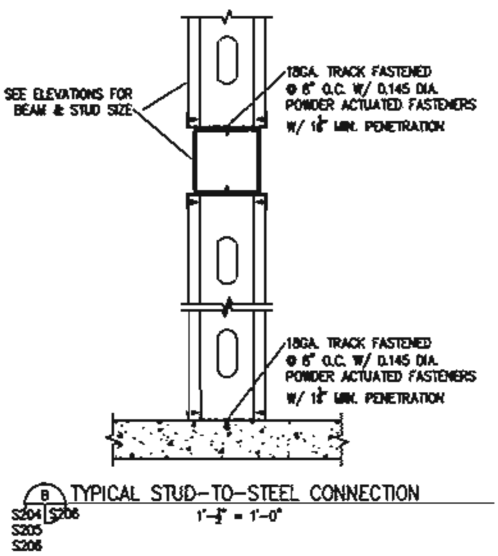
In cases where interruption of facility operation is not practical, exterior retrofitting techniques must be used. For these cases large soil embankments have been constructed to deflect potential blast pressures. While this is an effective protection method, adequate space is not often available. As a low cost alternate, pre-cast concrete wall panels are examined. These panels are widely produced in the United States, and can be fabricated and installed in a short time period. The large mass associated with the panels gives them ideal characteristics for blast resistance.

The research study examines the performance of this retrofitting technique and the predictability of the designed response.

Wall Systems

Un-retrofitted Wall

The un-retrofitted wall system examined consists of traditional steel studs as an infill. The wall consists of 8-in. deep steel studs used as an infill in a steel tube frame building system. The studs are attached to the building system through an 18 gage track fastened to the reinforced concrete ground slab and a hollow structural section at the top. Powder-actuated fasteners are used to attach the track to the floor and frame beams. The studs are connected to the track using self tapping bugle head screws. Studs are spaced at 16-in. on center. The wall construction sequence is shown in Figure 1.

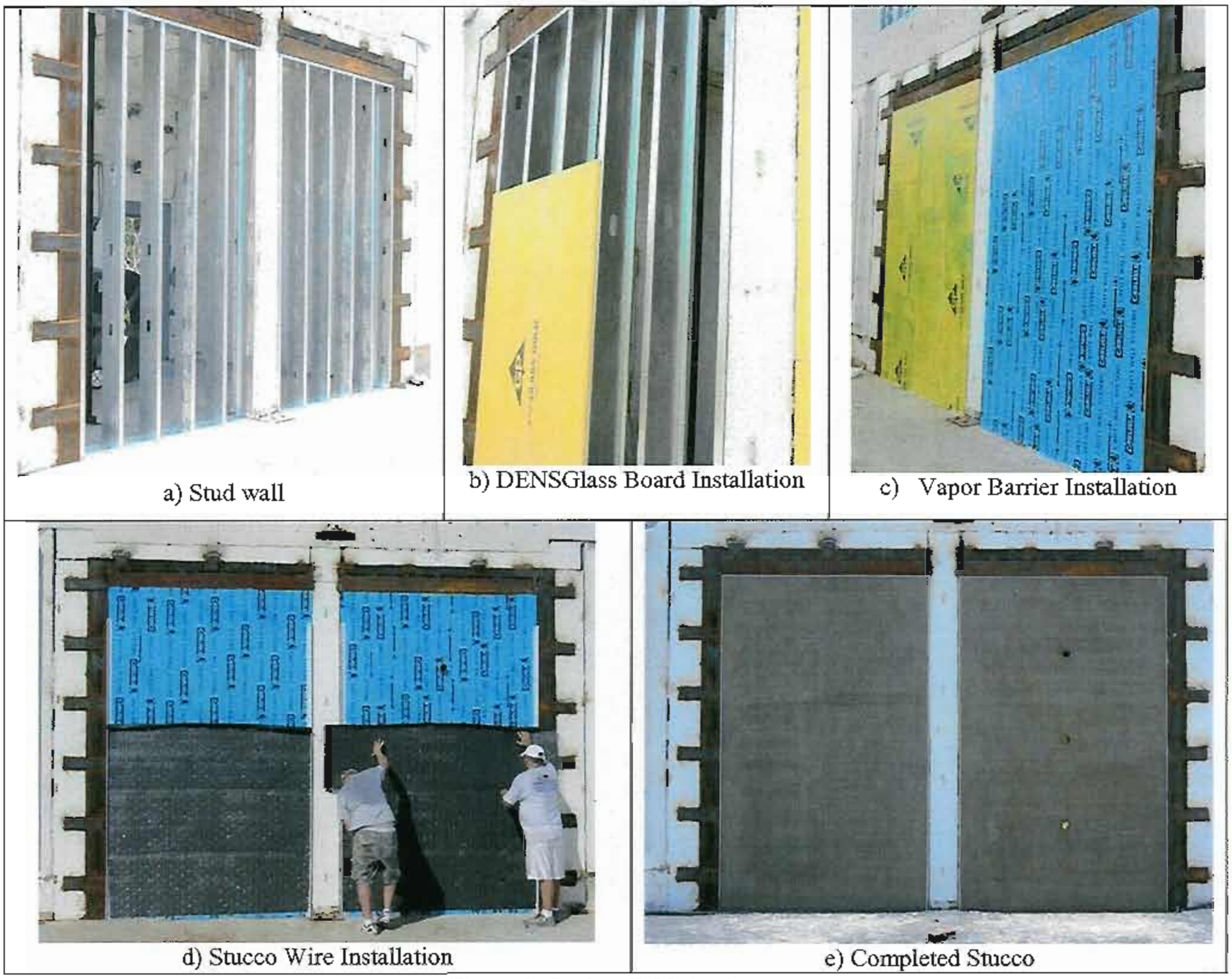


a) Wall elevation

b) Track detail

c) Track – stud connection

Figure 1: Stud connection details



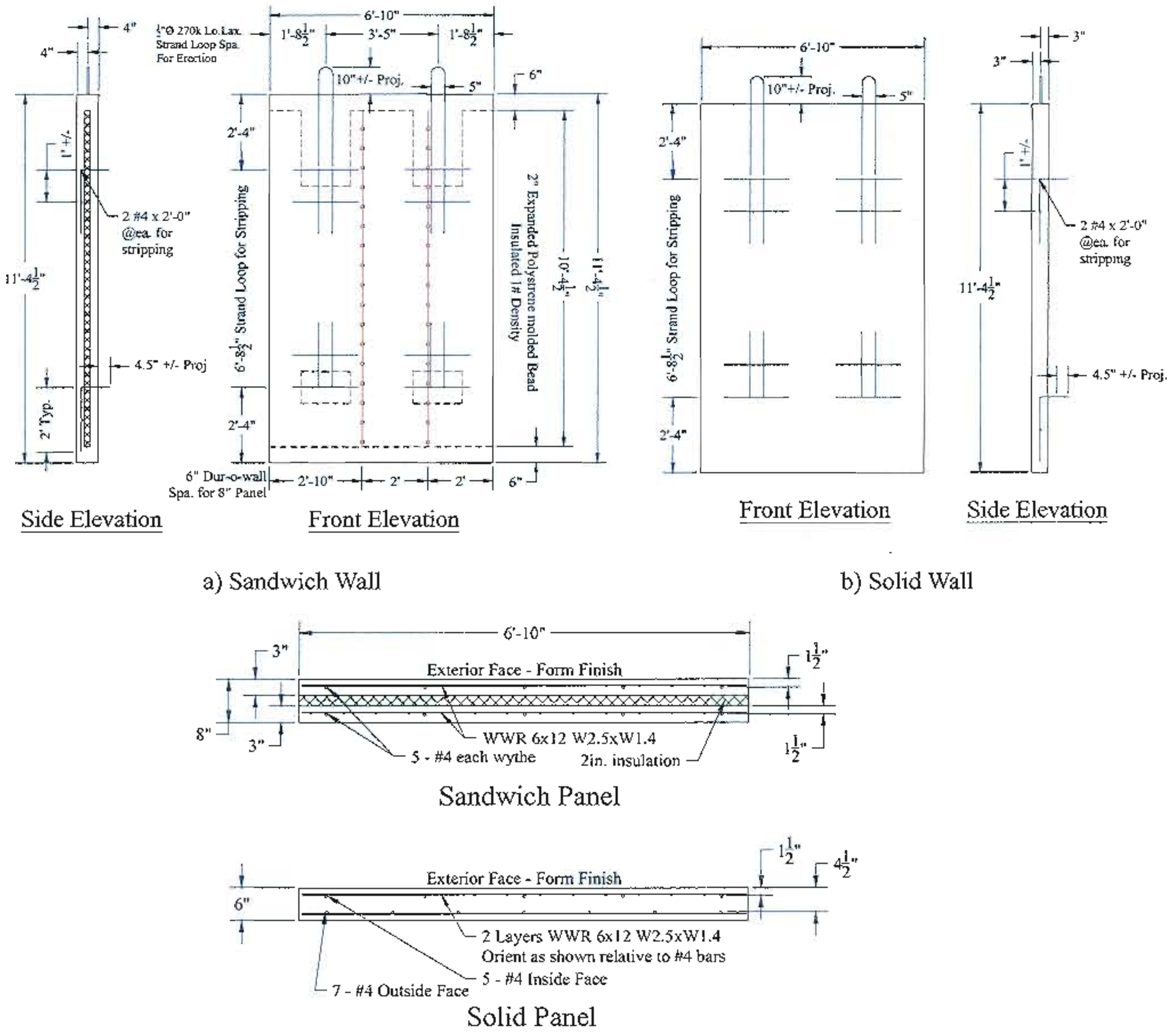
a) Stud wall
b) DENSGlass Board Installation
c) Vapor Barrier Installation
d) Stucco Wire Installation
e) Completed Stucco

Figure 2: Stud wall fabrication

Precast Concrete Wall Protection

Two precast concrete wall panels are examined as a retrofit method for buildings with weak exterior wall panels. The walls are designed to be installed outside of the building structure with attachments at the foundation and at the level of the building beam frames. This method of construction eliminates the need to interrupt the operations ongoing in the building. The two wall panel details are commonly used for precast building construction in the US. The panels examined are 136.5 in. tall and are used to span from the floor slab to the top of the first floor. These panels can be fabricated in lengths in excess of 30ft tall and are typically limited by highway allowances during shipping. The panels are used over one bay opening of 82 in. wide.

Two precast panel configurations are examined. The first consists of a sandwich wall panel made of conventionally reinforced interior and exterior wythes and an expanded polystyrene insulation layer. The interior and exterior wythes are connected to each other using steel reinforcing.



c) Sections

Figure 3: Precast concrete panel details

Level of Threat

The wall system is examined for two blast levels. The corresponding reflected pressure and impulse for these are shown in Table 2.

Levels of Protection (LOP) are defined in accordance with the Unified Facility Criteria 4-010-01 (22 Jan 2007) and described in Table 1. For this case, the supporting building framing will have minimal damage while the walls themselves will have significant damage. The metal stud walls are expected to maintain at least a "low" Level of Protection. The goal of the wall retrofit is to increase the system to a "Medium" Level of Protection.

Level of Protection	Potential Structural Damage
Very Low	Heavily damaged - onset of structural collapse: Major deformation of primary structural members, but progressive collapse is unlikely. Collapse of secondary structural members and non-structural elements
Low	Damaged - unrepairable. Major deformation of secondary structural members and minor deformation of primary structural members, but progressive collapse is unlikely. Collapse of non-structural elements.
Medium	Damaged - repairable. Minor deformations of secondary structural members and no permanent deformation in primary structural members. Major deformation of non-structural elements.
High	Superficially damaged. No permanent deformation of primary and secondary structural members or non-structural elements.

Table 1. Levels of Protection as defined by UFC 4-010-1 (22 Jan 2007)

Experimental Program

Two explosive full scale detonations were conducted on the steel stud and precast concrete wall panels at Alpha Range of Air Force Research Laboratory at Tyndall AFB, Florida. Two wall sets were examined:

- Experiment 1 - Steel Stud Wall (Left Opening) and Steel Stud Wall w/ Sandwich Precast Concrete Wall Panel (Right Opening)
- Experiment 2 - Solid Precast Concrete Wall Panel (Left Opening) and Previously Protected Steel Stud Wall (Right Opening)

As noted above, the stud wall used in the second detonation was also tested in the first. The damage to the stud panel after the first detonation was limited to hairline cracking on the face of the stucco; no damage to the interior drywall was visible.

The instrumentation consisted of three external reflected pressure gages at the front face of the test structure, an internal pressure gage located on the back wall of the chamber, five to six displacement gages attached to the interior face of the walls, and a free field pressure gage to measure overpressure. A series of strain gages were affixed to the pre-cast concrete connectors.

Figure 4: Test Structure Pretest 1

		Analytical Prediction	Measured	Percent Difference
Experiment 1	Max Reflected Pressure (psi)	8.3	11.4	27.2
	Impulse (psi-ms)	79.2	72.4	-9.4
Experiment 2	Max Reflected Pressure (psi)	32.4	29.7	-9.09
	Impulse (psi-ms)	209	187.97	-11.19

Table 2. Blast Demands

Steel Stud Wall, Experiment 1

Initially, the steel stud system was modeled using property values contained in SBEDS for the 8-in steel stud system – a common variety specified through industry nomenclature. Additional mass was added to the model to replicate the mass effects of the sheathing, vapor barrier, and stucco systems (14.62 lbf/ft^2). The support connections could be characterized either as "fixed-fixed" or "simple-simple" because the stud ends are squarely placed against the track plates to prevent rotation, but are thin enough to cripple (and potentially rotate) easily.

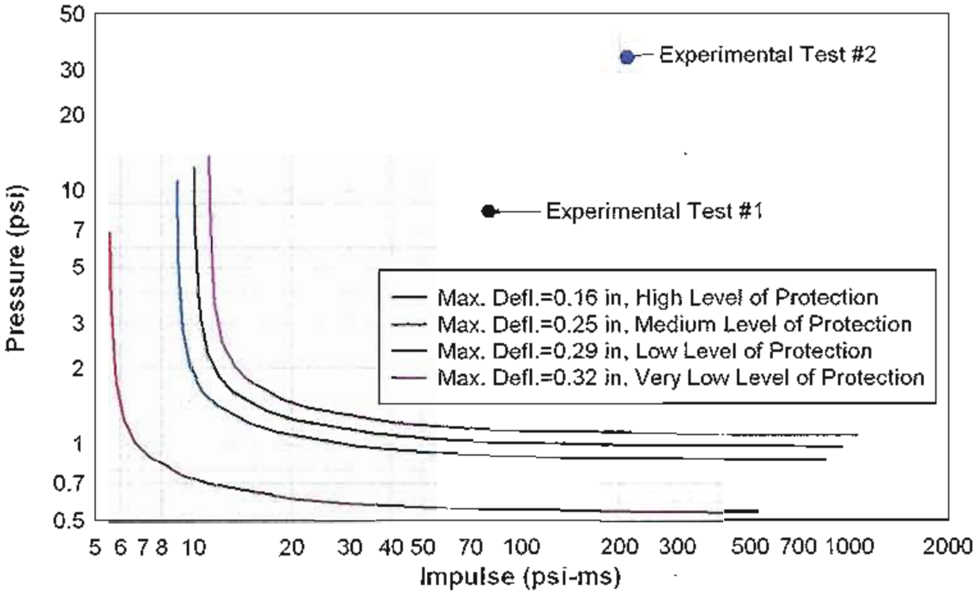


Figure 5. PI Diagram of Metal Stud Wall

For the first test, (500lbs at 136 feet standoff), SBEDSs provided a maximum displacement estimate of approximately 9.5 inches and a steady-state displacement of approximately 2.5 inches, which placed it in the "failure" zone based on the Levels of Protection (LOPs) used by the Dept of Defense – see Figure 5.

Because of the predicted high deflection and the corresponding "very low level of protection", the steel stud wall for the first test was expected to have catastrophic failure and/or collapse. The pictures in Figure 6 show the wall system immediately after the blast test. The stucco exterior showed much cracking and buckling but for the most

part held together. The top connection separated (up to 1.5 inches) in the center but remained connected at the ends; the lower connection however sustained very little damage and almost completely retained its integrity. The interior sheathing appeared to separate from the studs in one location apparently due to the inertia, but the majority of the covering remained intact. While the wall had significant damage/deflection, for the most it appeared to adequately protect the structure interior during the blast and continued to offer some physical resistance afterwards. Cleanup efforts to remove the wall after the blast confirmed there was still significant resistance/connectivity in the wall.

a) Cracking and buckling of the stucco

b) Separation of the stud wall from the ceiling of the structure

c) Ground level connections and studs showed little damage

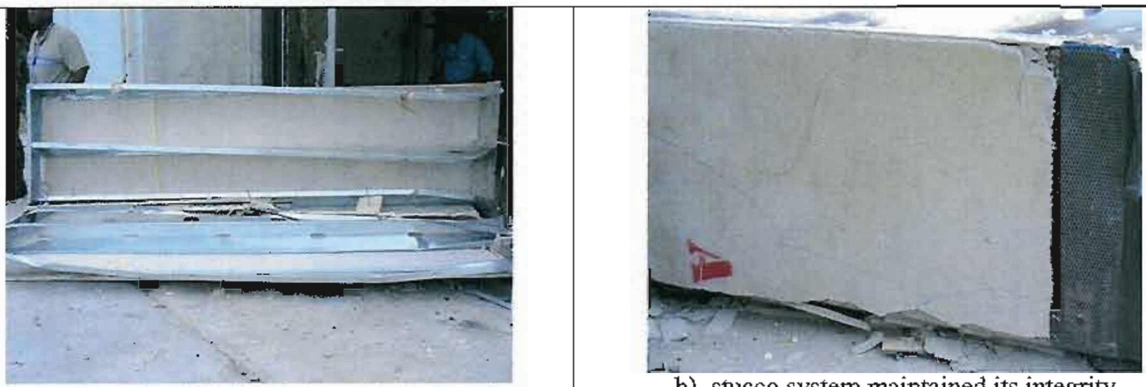
d) Connections at the ceiling showed substantial stud crippling and separation

Figure 6. Metal stud wall pictures from Test 1.

Metal Stud Wall, Experiment 2

The second experimental stud wall test resulted in complete wall blowout/failure - as shown in Figure 7. Upon impact with the blast wave, the wall system moved back as one unit until it impacted the displacement gauge pole. The wall then fell forward into the opening it had just been connected to. The stud tracks screws appeared to have sheared relatively cleanly.

Interestingly, while the stucco system had some cracking, it managed to stay mostly intact and did not disintegrate and separate from the mesh and/or studs. This generally confirms the first test results: the ductile materials in the stucco system (steel lath, tough vapor barrier, and fiberglass sheathing) bring significant resistance to the wall. Overall, the wall provided a "low" or "very low" Level of Protection.



a) metal stud wall fell back through the opening

b) stucco system maintained its integrity

Figure 7. Picture of Metal Stud Wall Immediately after Test 2

Precast Concrete (Sandwich) Wall, Experiment 1

Qualitatively, the pre-cast concrete wall panel sustained minimal damage and appeared to retain its structural capacity after the test as shown in Figure 8. The only visible damage was several small cracks in the exterior concrete.

a) Pre-Cast Test 1 immediately after blast

b) Pre-cast (solid) concrete panel immediately after Test 2.

c) Significant lateral cracking after test 2

Figure 8. Post test photos of the precast concrete panels

Precast Concrete Wall (solid), Experiment 2

The pre-cast concrete slab photos of the second blast test are located in Figure 8a. The solid pre-cast concrete sustained substantial cracking but remained essentially intact. Figure 8c shows numerous lateral cracks over the entire interior span of the panel; the exterior side had some cracking but less than the interior. Some spalling of the

interior concrete was evident near the bottom. The precast slab appeared to retain significant resistance. The precast concrete slab provided at least a "medium" level of protection to the covered metal stud wall.

Protection

The precast wall panels were able to reduce the maximum displacement of the original stud wall beneath (and potentially protect any assets of value within a facility). Figure 9 shows the dramatic drop in maximum displacement between the protected wall (1 inch) and the unprotected wall (6 inches). Clearly, some pressure wave still gets beyond the precast barrier, but it is much less.

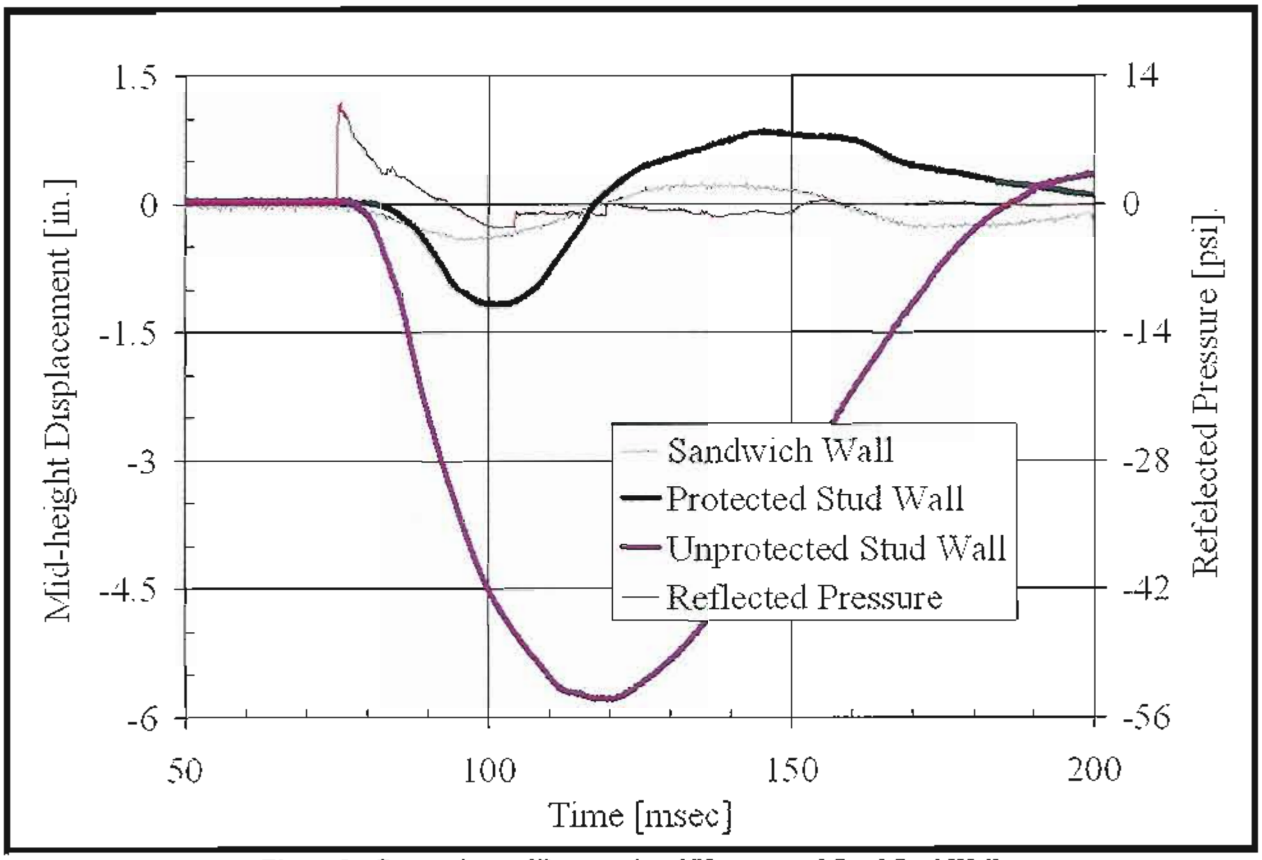


Figure 9. Comparison of Protected and Unprotected Steel Stud Wall

Conclusions

The results from the research provide several interesting key conclusions.

- The Pre-cast concrete wall panels can provide a viable means of enhancing the protection of conventional exterior walls. In both the low and high level experiments, the pre-cast wall panels reduced both the displacement of the protected walls and the interior pressure of the space. These phenomena would clearly be key to reducing injury to personnel and damage to equipment and facility. The pre-cast wall panels also appeared to have sufficient residual resistance (in either type of pre-cast wall panel) to absorb a secondary blast.

- The Levels of Protection as defined for the steel studs seem too conservative for practical application. The required maximum displacement for a Very Low Level of Protection (or blowout/failure) is relatively low. From the test at a low blast level (Test 1), the wall was still standing with substantial resistance and would still be categorized as "blowout/failure".

- Standard precast concrete connections perform well under blast demands but provide rotational resistance to the response.

- Stud wall construction with stucco provides elevated blast resistance due to the ductile materials used (metal lathe, vapor barrier, fiberglass sheathing) and mass of the stucco itself. In both tests, the normally brittle stucco material held together - with significant cracking. It is believed the layered or sandwich effect plus the organic ductility of these materials increased the ductility of the system and provided increased integrity.

- At elevated demands the connection details used in stud construction will cause severe failure of the wall.

Recommendations

Additional research that examines the response of the pre-cast connections at higher blast loads would be beneficial. Existing static design criteria and criteria optimized for blast response could be tested and/or modeled. Also, there would be value added to test a pre-cast wall panel multiple times to show its resistance decreases with fatigue.

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